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ANALYSIS OF BLAST HOLE DRILLING AT SIBERIAN OPEN PIT MINES

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ABSTRACT

This article presents operational data and their statistical analysis for open pit mines in Krasnoyarsk krai and Khakassia. Evaluation criterion of operation efficiency of drilling machinery is presented together with its actual values. Specific costs of drilling rig operation and unit costs of drilling tools per 1 linear meter (LM) of drilled well are presented. The structure of prime cost of machine shift of rig operation is described. Operation efficiency of drilling machinery is analyzed for some Siberian mining companies on the basis of field trials: AO Polyus, AO Rusal–Achinsk, Gorievski GOK (mining and processing company), as well as Chernogorsk, East Beiski and Izykhski opencast coal mines (Khakassia). It has been determined that Russian drilling rigs are less mobile and efficient in comparison with foreign analogs. However, this drawback is compensated by significantly lower cost of the machinery and low unit costs of well drilling per 1 LM. Appropriate recommendations are given.

KEYWORDS: Drilling Rig, Drill Bit, Drilling Technique, Specific Costs, Drilling Efficiency, Drill Bit Resistance & Operation Efficiency

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Original Article

INTRODUCTION

Mining industry is the basis of all commercial manufacturing, it carries out extraction of mineral resources and supplies feedstocks not only for Russia but for other countries as well. The main amounts of rock are prepared for extraction by drilling and blasting, one of the main constituent processes is blast hole drilling [1–3].

From the main drilling procedures applied at the Russian open pit mines – rotary roller drilling, rotary cutting drilling, and percussive rotary drilling – the roller drilling is the most widely applied [4], its portion amounts to 80-85% of all drilling activities. At open pit mines of iron ores and nonferrous metals presented mainly by hard rocks, the roller drilling amounts to 90–95%, at coal mines – about 60%.

At present, it is believed that the rigs of Atlas Copco, Tamrock, Reedrill and other Western companies are more preferred in comparison with SBSh-250MNA-32 rig due to diesel drive which makes them independent on power cutoff at open pit mine and provides advantages upon rig relocation from one drilling site to another.

Blast hole drilling at Russian open pit mines of iron ores is carried out by about two hundred rigs of roller drilling, one hundred and sixty rigs are fabricated by UGMK-Rudgormash (Voronezh), ten rigs – by Izhorsk plant and Atlas Copco, each, five rigs – by Tamrock company, and four rigs – by Reedrill company.

Major foreign companies at open pit mines apply roller rigs [5–8], together with percussion rigs [8–11].

The main manufacturers of roller rotary rigs are Atlas Copco, Bucyrus, Sandvik-Tamrock-Driltech, Harnischfeger or P&H. These companies developed rigs for rotary drilling of vertical and inclined wells with the diameter up to 560 mm, though the main diameter is up to 320 mm.

Modern rig designs are equipped with hydraulic actuators, which decreases total weight, provides wide scale variations of specifications, easy control and comparatively simple maintenance. Foreign companies generally propose to customers wide range of drilling diameters, rod lengths and diameters, possible drilling depths (with or without connection of drilling assembly), powers of primary drive, compressor flow rates, etc.

The most popular manufacturers of universal drilling rigs of light and medium class are Atlas Copcoand Sandvik-Tamrock-Driltech. The rigs of these companies are equipped with single primary actuator (diesel engine or high voltage electric motor) which powers compressor and pump station. The latter one powers all drives and assemblies of the rig, thus, one operator could be involved. Atlas Copco manufactures a set of nine models completely equipped with hydraulic actuators.

While evaluating efficiency of rigs for blast hole drilling at open pit mines, peculiar attention should be paid to design specifications, operation modes and conditions of roller bits [12–15].

Roller bit (RB) is a multicomponent unit based on the principle of free rotation of several (three as a rule) rollers on independent axles (roller bearings). RB is comprised of welded sections where on bit leg axle assembled rollers rotate, thus making solid unit, so that in the case of failure of one roller or its bearing, overall RB is inoperative.

High efficiency of roller drilling in hard rocks can be attributed to high surface area of RB and high contact pressures of teeth on rock [16–17]. These design features provide high wear resistance of RB and possibility to apply higher powers and contact loads to mine face exceeding rock contact strength. In addition, roller drilling requires for high axial loads, power, rig weight, and has higher cost.

In general, the bearings fail due to penetration of rock fines through gap between roller and leg into bearing cavity, which results in settling of cuttings, increased wear of bearings, decrease in bearing strength and jamming [18–19], however, the main disadvantage of RBs is poor adaptation of certain RB design to variation of properties of drilled rocks, which necessitates operation with numerous RB types, and it is unreasonable to replace them under conditions of open pit mine during drilling of short wells contrary to deep drilling (oil and gas). Herewith, while drilling complex benches, the advantages of roller drilling can be lost.

Therefore, the authors believe that it is necessary to develop and to substantiate peculiar approaches to selection of optimum RB designs for open pit mines including the use of tooth-disk rollers, cutting rollers, and other combinations. However, these advanced solutions are not widely applied up till now.

At present, about 200 cone drilling machines are in operation at quarries and sections in Russia, of which 80% are of domestic production (UGMK-Rudgormash, Izhora Plant, etc.) and 20% are made by foreign firms (Atlas Copco, Sandvik, Tamrok and others) [20-21]. There is a small number of rotary percussion drilling machines.

A number of studies show that Russian drilling equipment of the leading public corporations Rudgormash and Buzuluk Heavy Machine Building Plant (SBSh-250-MNA-32, SBSh-190-250-60, 3SBSh-200-60, 6SBSh-200-32, etc.) is, for the most part, not competitive. Its main drawback in comparison with the best foreign counterparts is low reliability.

The practical data of a number of consumers concerning the operation of drilling equipment are not consistent with the opinion of individual experts (mainly representatives of Western companies) that foreign drilling rigs are much more efficient than Russian ones.

However, with these shortcomings, Russian-made drilling rigs of the SBSh type, when drilling strong rocks, are not inferior to foreign drilling equipment in terms of average annual productivity. In [22], drilling performance at the public company Appatit for 2003 is presented (Table 1).

Table 1: Drilling Performance at the Public Company Appatit for 2003

Drilling Machine Brand	Annual Fund of Working Hours, h	Utilization of Working Time, units	Performance, pm/year	Average Productivity, pm/h
Vostochny Mine				
SBSH-250-MNA-32 Rudgormash	5,801	0.7	53,300	13.13
D-60KS Tamrock №5	5,449	0.7	50,116	13.14
D-60KS Tamrock №6	5,644	0.7	59,949	15.17
Tsentralny Mine				
SBSH-250-MNA-32 Rudgormash	5,950	0.68	61,792	15.27

Source: [22].

In order to obtain objective information about drilling machinery under actual conditions, the authors performed commercial study at mining companies of Krasnoyarsk krai and Khakassia.

METHODS

Roller method of blast hole drilling is the most preferred based on application of Russian and foreign drilling rigs and tools. In recent decade, the considered companies operate machinery summarized in Table 1 [23-24].

The operation efficiency of drilling rigs is determined by specific costs C per 1 LM of blast holes according to the equation:

$$C = C_1 + C_2 = \frac{C_{ms}}{Q_{sh}} + \frac{C_{rb}}{l_{rb}} + \frac{C_{rod}}{l_{rod}}, \text{ rub/m} \tag{1}$$

where C_1 is the specific costs of drilling rig operation related to 1 LM of drilled well, rub/m; C_2 is the specific costs of drilling tools related to 1 LM of drilled well, rub/m; C_{ms} is the cost of machine shift of drilling rig, rub/sh; Q_{sh} is the shift productivity of drilling rig, m/sh; C_{rb} is the RB cost, rub; l_{life} is the RB operation lifetime, m; C_{rod} is the drilling rod cost, rub; l_{rod} is the rod operation lifetime, m.

Specific costs of drilling rig operation related to 1 LM of drilled well are determined as follows:

$$C_1 = \frac{C_{ms}}{Q_{sh}}, \text{ rub/m.} \tag{2}$$

The cost of machine shift of drilling rig is determined as follows:

$$C_{ms} = C_{lc} + C_{dep} + C_{en} + C_{tm} + C_m, \text{ rub,} \tag{3}$$

where C_{lc} is the labor cost of drilling rig crew, rub/shift; C_{dep} is the depreciation expenses, rub/shift; C_{en} is the cost of electricity and diesel fuel, rub/sh; C_{tm} is the cost of maintenance of drilling rig, rub/shift; C_{m} is the cost of auxiliary materials used for drilling, rub/shift.

Specific costs of drilling tools related to 1 LM of drilled well are determined as follows:

$$C_2 = \frac{C_{rb}}{l_{rb}} + \frac{C_{rod}}{l_{rod}}, \text{rub/m}, \qquad (4)$$

where C_{rb} and l_{rb} are the cost (rub) and operation lifetime (m) of roller bit, respectively; C_{rod} and l_{rod} are the cost (rub) and operation lifetime (m) of drilling rod.

RESULTS

The experimental results and predictions are summarized in Table 2.

Table 2: Operation Performances of Blast Hole Drilling at the Considered Mining Companies

f	Drilling Rigs	Q_{sh}, m/sh	C_1, rub/m	Drilling Tool	L, m	C_2, rub/m	C, rub/m
Chernogorsk opencast coal mine							
6–10	SBSh-250/270-60	296.3	217.37	JUNJIN – 269	12,436.5	12.92	227.95
	SBSh-250MNA-32	308.8	177.41	Atlas Copco – 269	6,820	21.22	195.27
	SBSh-250D	368.4	207.13	TKZ-PV – 269	2,488.4	20.31	23.27
	AtlasCopcoDML	430.1	233.25	Atlas Copco – 229	12,990.5	9.04	246.47
Izykhski and East Beiski opencast coal mine							
6–10	SBSh-250-MNA-32	316.1	173.26	TKZ-PGV – 250.8	6,228	78.19	249.92
				MGPV – 250.8	3,183.5	120.6	293.10
	Atlas Copco DML	331.9	302.26	JUNJIN 632Y – 215.9	9,800	77.82	381.46
				JUNJIN SA-SM635 – 215	11,000	79.05	382.59
				TZ-PGV – 215.9	6,899	66.55	372.97
AO RUSAL Achinsk							
8–10	SBSh-250MNA-32	257.5	212.09	TKZ-PGV – 244.5 (GluBur)	517.4	70.58	281.93
				TKZ-PGV – 244.5 (GorMash)	951.7	36.73	248.08
				TZ-PV – 215.9 (UralBurMash)	866.2	19.16	229.16
				TKZ-PGV – 215.9 (GorMash)	1,541.8	36.79	246.29
Gorievski GOK							
10–12	SBSh-250MNA-32	255.9	88.52	TKZ-PGVSh2.35UMN – 244.5	1,000	48.90	137.33
	Atlas Copco DML	443.3	123.2	TZ-PGV – 125	1,531.1	30.59	154.39
PAO POLYUS Olimpiadinski GOK							
9–15	SBSh-250-MNA-32	383.8	56.40	TKZ-PGV – 244.5	573.3	118.74	175.07
				TKZ-PGVSh2.35UMUR1 – 244.5	815.1	87.0	143.49
				AIRP632 (R981) – 244.5	776	91.08	122.71
				AIR632 (R981) – 244.5	733.4	93.65	149.98
				AIR 637 (R976) – 244.5	1,814	36.97	92.93
				AIR637 (R2029) – 244.5	1,278	52.88	108.84
				AIRP637 (R2029) – 244.5	1,346	51.26	107.22
				AIR637 (R982) – 244.5	1,627	42.43	98.26
	Atlas Copco DML	411.2	133.63	TKZ-PVSh2.01UN – 215.9	1,105.2	46.43	182.24
				TKZ-PVSh20U – 215.9	1,594.8	35.11	169.66

				TKZ-PVSh1.44UNL – 215.9	287.5	39.73	175.54
				TKZ-PVV-ACSX-R1336 – 215.9	1,311.3	41.21	175.77
				TKZ-PGVSh19U – 215.9	1,697.3	29.82	167.52
				TKZ-PGVSh19.01U – 215.9	1,920.3	27.03	155.62
	Atlas Copco Pit Viper 235	456.8	133.19	AIR632 (R980) – 215.9	2,584.7	27.65	156.25
				AIRP632 (R980) – 215.9	2,199.3	34.32	162.92
				TKZ-PV V-ACS62X-R1381– 215.9	839.1	84.41	217.35
				TKZ-PVSh2.36UNA – 244.5	760.8	83.75	217.02
				AIRP727 (R976) – 250.8	2,238.5	36.39	168.54
				TKZ-PGVSh2.35UMR1 – 244.5	815.1	87.81	220.75
				AIRP637 (R982) – 244.5	1,283	55.70	184.22
				AIR637 (R982) – 244.5	1,627	42.30	187.85

Remarks

Abbreviated notations: f - Protodyakonov scale of hardness; Q_{sh} - shift production rate of drilling rig, m/sh; C_1 - specific costs of drilling rig operation, rub/m; L - average sinking (life) of drilling bit, m; C_2- specific costs of drilling tool related to 1 LM of drilled well, rub/m; C - specific costs for drilling of 1 LM of blast holes, rub/m.

Specific costs for operation of drilling rigs related to 1 LM of drilled well are based on their design productivity rate with consideration for physicomechanical properties of drilled rocks according to the equation:

$$Q_{sh} = \frac{T_{sh} \cdot k_u}{\frac{60}{V_{dr}} + t_{aux}}, \text{ m/sh} \tag{5}$$

where T_{sh} is the shift time, min; k_u is the use factor of drilling rig per shift, k_u = 0.75–0.9; V_{dr} is the drilling rate, m/min; t_{aux} is the time of auxiliary operations.

The time for auxiliary operations is determined as follows:

$$t_{aux} = \frac{t_{rel} + (t_{rc} + t_{dad}) \cdot (n_{rn} - 1)}{l_{well}} + \frac{t_{rbr}}{l_{rblt}}, \tag{6}$$

where t_{rel} is the time of relocation and mounting of rig on well axis, min; t_{rc} is the time of rod connection, min; n_{rn} is the number of rods per one well, units; t_{dad} is the time of disconnection of drilling assembly, min; l_{well} is the well length, m; t_{rbr} is the time of RB replacement, min; l_{rblt} is the RB operation lifetime, m.

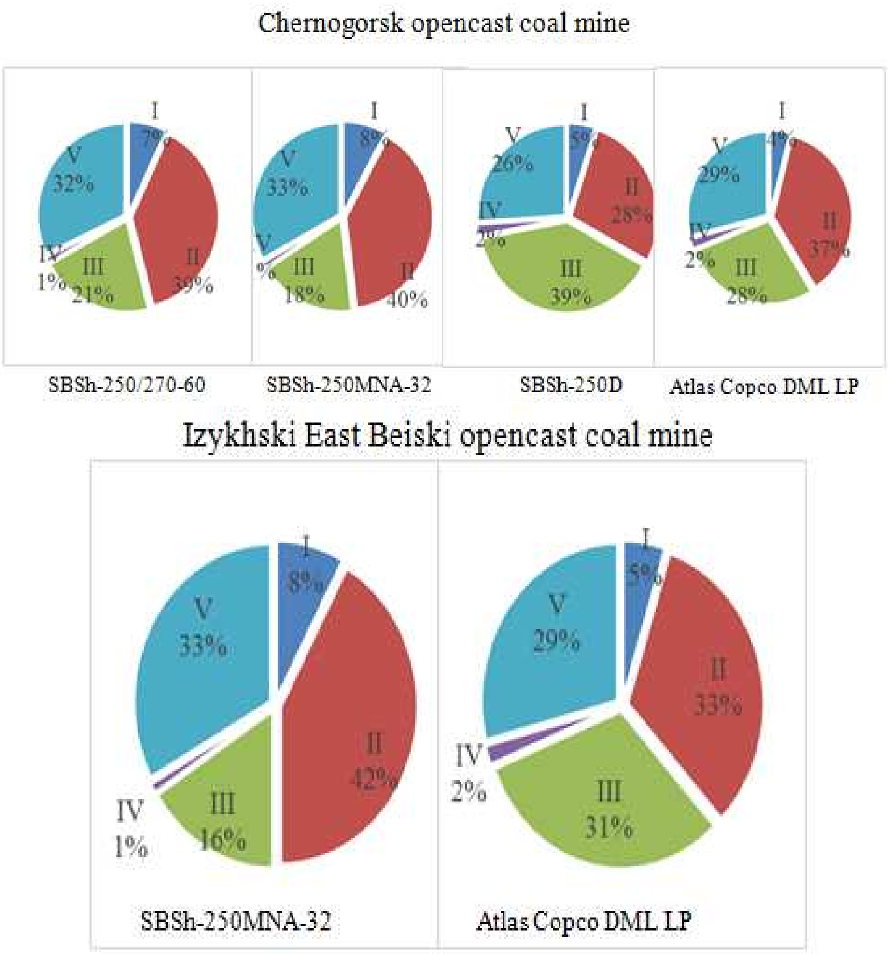
It follows from Table 2 that:

- At Chernogorsk coal mine, the obtained results evidence preferred selection of SBSh-250-MNA-32 rig with AtlasCopco - 229 bit.
- At Izykhski and East Beiski coal mines, the obtained results evidence preferred selection of SBSh-250-MNA-32 with TZ-PGVbit for wells with the diameter of 215.9 mm and TKZ-PGV bit for wells with the diameter of 250.8 mm.
- The experimental results for AO Rusal–Achinsk evidence preferred selection of SBSh-250-MNA-32 rig with TZ-

PVbit for wells with the diameter of 215.9 mm and TKZ-PGV bit for wells with the diameter of 244.5 mm, which is attributed to lower specific costs related to 1 LM of drilled well in the case of the considered drilling tool.

- At Gorievski GOK, the obtained predictions evidence preferred selection of SBSh-250-MNA-32 rig with TZ-PGV-125 bit.
- The experimental results for AO POLYUS evidence preferred selection of SBSh-250-MNA-32 rig with TKZ-PGVSh19.01U bit for wells with the diameter of 215.9 mm and AIR637 (R976) bit for wells with the diameter of 244.5 mm.
- Analysis of operation of drilling machinery at the considered companies reveals that the Russian drilling rigs are characterized by lower specific costs (C_1) than those of foreign rigs by 15–25% in average.

Predictions of specific costs for operation of drilling rigs (Figure 1) related to 1 LM of drilled well demonstrate that the main cost items are depreciation expenses, costs of electricity or diesel fuel, and maintenance costs. The analysis shows that the costs of power (electricity and diesel fuel) are the highest. Hence, specific depreciation expenses, costs of electricity or diesel fuel, maintenance costs for Russian drilling rigs using electricity and foreign rigs using diesel fuel evidence reasonability of the Russian drilling rigs with electric drive. At the considered companies, the SBSh-250 rigs with electric drive are characterized by 2.5–2.8 times lower cost of machine shift than that of foreign analogs with diesel drive.



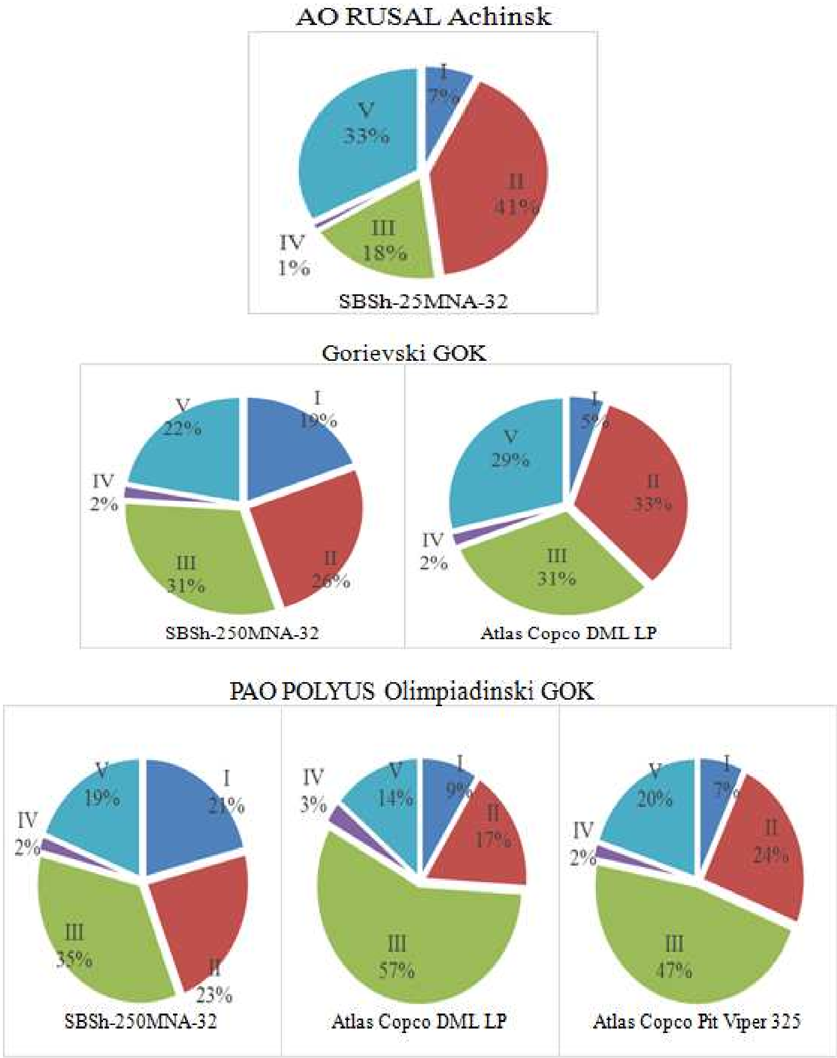


Figure 1: Cost Structure of Machine Shift of Drilling Rig at the Considered Companies: I – Shift Labor Cost, rub/shift; II – Shift Depreciation Expenses, rub/shift; III – Expenses for Electricity or Diesel Fuel, rub/shift; IV – Expenses for Auxiliary Materials for Drilling, rub/shift; V – Expenses for Maintenance, rub/shift.

DISCUSSIONS

The following conditions have been used in the study:

- The considered drilling rigs at each mining company are new and are at initial stage of operation. Average inventory cost of each type of drilling rig is taken based on costs of machinery and its delivery from manufacturers to operation sites.
- The rock hardness range for each considered company was defined individually according to geological and physicomechanical properties of rocks.

It can be seen that the Russian drilling rigs with electric drive are characterized by significantly lower productivity rate (by 20–30%) in comparison with foreign analogs. This could be attributed to the fact that the Russian fleet of drilling machinery is comprised of obsolete roller drilling rigs characterized by lower power capacity, lower range of drilling diameters, as well as obsolete rotary supplying mechanisms. Thus, hydraulic and hydro-pneumatic mechanisms supplying

drilling assemblies to mine face do not provide smooth adjustment of drilling modes (especially axial load), which creates impact loads on drilling tools and significantly decreases reliability of drilling tool, especially at drilling of complex rock arrays.

SBSh-250/270-60 (RD10) drilling rig with cable system of drilling assembly supply to mine face proved to be good, this system provides smooth adjustment of axial loads.

Foreign drilling tools (Atlas Copco, JUNJINand others) are characterized by significantly higher reliability (by 45–55%) in comparison with the Russian analogs. This can be attributed to higher fabrication quality of rig components and drilling tools as well as to higher attention to selection of RB materials.

It should be mentioned that the rocks with $f \leq 6–10$ according to Protodyakonov scale of hardness are the most widely distributed at the Russian open pit mines. Cutting and cutting rotary drilling tools demonstrated the best performances in these rocks; operation of these tools improves performances of drilling activities. However, these tools are not widely applied for drilling of soft and medium rocks due to insufficient attention of both manufacturers and mining companies.

Based on the obtained results, as well as taking into account the shortcomings of modern commercially available roller cone bits (which are non-separable), the Department of Mining Machines and Complexes of the Siberian Federal University is carrying out work to upgrade the already known and create new highly-effective types of maintainable drilling tools for cutting, cutting-rotating and combined action, having an increased resource of basic parts and providing high productivity. Moreover, the Department is working on lowering the technical and economic indicators of drilling explosive wells, especially in the coal mines of Russia, the Krasnoyarsk Territory and the Republic of Khakassia in particular.

CONCLUSIONS

The following conclusions have been obtained:

- Atlas Copco DML drilling rigs are the most efficient in terms of production rate at all considered companies, they are more mobile and do not depend on electric network of open pit mine.
- Production rate of Russian drilling rig SBSh-250D (AO Rudgormash) with diesel drive is insignificantly lower than that of foreign machinery (14-15 %). However, this drawback is compensated by lower cost of the rig and maintenance expenses.
- The cost of machine shift of Russian drilling rigs is significantly lower than that of foreign analogs. At all considered companies, the lowest cost of machine shift is that of SBSh-250-MNA-32, and the highest cost is that of Atlas Copco DML.
- The lowest specific costs for drilling of 1 LM of well at all considered companies are for operation of SBSh-250-MNA-32, and the highest – for Atlas Copco DML, which mainly depends on high costs of machine shift and cost of acquisition.
- Production rate of Russian drilling rigs can be probably increased by replacement of electric drive with diesel electric drive. Thus, during relocation of drilling rig from one level to another, it would be possible to run diesel engine, and during drilling – electric drive.

- Foreign drilling rigs are characterized by double costs and life in comparison with Russian drilling tools. This is mainly stipulated by higher production quality and high strength materials.
- Efficiency of blast hole drilling depends on life and costs of drilling tools. Therefore, it is required to develop new cost efficient and high strength drilling bits. Taking into account that drilling bits fail mainly due to failures of bearings, it would be reasonable to design and to fabricate maintainable drilling tools with multiple use of working elements, to improve demountable cutting and routing drilling tools which provide cutting, cleaving, and shearing of rocks in well.

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